Carbon Footprint Analysis of a Polymer Manufacturing Process

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ABSTRACT

This paper describes a carbon footprint (CF) analysis of a manufacturing process based on large scale polymer food tray production using Polyethylene Terephthalate (PET). The methodology utilised, allows for the calculation of the CF, in accordance with PAS (Publically Available Specification) 2050, of a 16.6g recycled PET (rPET) tray, based on a cradle-to-grave life cycle. Using an Irish plastics manufacturer as the experimental basis for the research, primary activity data was measured for in-house processes while secondary data was used for upstream and downstream stages. The CF of a 16.6g rPET tray was found to be 23.42 g CO_2e or 1.4106kgCO_2e.kg^{-1} trays. The raw material inputs and manufacturing processes were found to contribute 45% and 33% of the greenhouse gases emissions (GHGs),respectively. The end-of-life stage was found to contribute 18% of the GHGs, while the secondary packaging and transport stages contributed only 2% each. By manufacturing the tray with 85% recycled content, the CF was found to be 60% lower compared to a benchmark based on only virgin materialutilisation. By increasing the end-of-life recycling rate from 22.5% to 32%, the CF was found to be reduced by 2%. Transport was found to have a minimal effect on CF.

KEYWORDS: Carbon Footprint, Manufacturing, Polymer

1. INTRODUCTION

With widespread growing concern over GHG emissions to the atmosphere, greater attention is being paid to the contribution of manufactured products to global warming. Increasingly, manufacturers are being expected to quantify product CFs as part of their manufacturing process in kg CO_2 equivalents (kg CO_2e). One area that is receiving considerable attention is packaging products in the food retail sector. In this sectorsupermarket chains are increasingly concerned with the CF associated with product packaging. As a result, they are demanding packaging manufacturers to CF their products, so that both supermarkets and consumers can differentiate between products based on CF data.Plastic packaging accounts for 50% of the CO_2 emissions arising from all packaging in EU-27[1], which in turn accounts for 3% of EU-27 total CO_2 emissions [2].

The Courtauld Commitment is an agreement between the Waste & Resources Action Programme (WRAP) and major UK grocery organisations that voluntarily sign up to the commitment. The targets of the Courtauld Commitment are to achievea 10% reduction in the carbon impact of grocery packaging and a 5% reduction in grocery packaging waste [3].Companies who have, to date, undertaken CF studies and/or reduction initiatives include, Wal-Mart, Coca-Cola, Unilever, Volvic, Evian, Walkers, Boots, Marks &Spencers, Dell and Tesco[45].

Previous plastic packaging CF studies include investigations into polypropylene food pots (0.567 kgCO_2e .kg^{-1})[6], PET water bottles (2.86 kg CO_2e .kg^{-1})[7], and PET strawberry containers (6.066 kg CO_2e .kg^{-1}) [8].Investigations into the impact of end-of-life management on the CF of plastic have found recycling to produce the least amount of GHGs, followed by landfill, and then incineration (with energy recovery) [789].

The contribution of transportation to the CF has been found to be relatively large when the transport associated with the food produce(filling) is included in the study. Transport associated with the filled packaging made up86% of the total CF for packaged strawberries [8], 28% for bottled water[7] and 28% for rPETtrays produced by Holfeld Plastics Ltdaccording to a Private Consultancy Report. These studies did not include the CF associated with the filling production; only its transport. When transport of the filling is omitted, the contribution of transport to the total CF is found to decrease significantly[8].

The inclusion of recycled content in plastic packaging products has been found to significantly reduce their carbon emissions; increasing the rPET content of bottles from a zero baseline to 50% and 100%, resulted in the total CO_2 emissions dropping by 13% and 27% respectively [10].

The current work is motivated by recent initiatives within the food retail sector to quantify the CF of food products, including packaging. The main goal of this study is to analyse a polymer manufacturing process, so that a robust methodology can be implemented by which the CF of the various manufactured products can be reliably and repeatedly quantified. In this paper, the methodology underpinning the calculation of the CF of one specific product line, namely an rPET tray is described and the important parameters (e.g., proportion of recycled content, end-of-life treatment and transport) associated with its production and life cycle are analysed and discussed.

2. METHODOLOGY

Holfeld Plastics Ltd., an Irish plastics manufacturer, is used as the case study for this work.

2.1 Manufacturing Process

There are three raw material inputs associated with the production process at Holfeld:

1. Recycled PET (rPET) flake from post-consumer bottles.
2. Amorphous PET (aPET) (virgin pellets).
3. Re-ground rPET (r-grPET) from in-house closed loop recycling of defect trays and other tray waste to give rPET flake.

The mixture of these three inputs (the proportions of which vary according to the product and available stocks) is then extruded into sheets of rPET. In this study, the recycled content input was split equally between r-grPET and rPET. Following extrusion, the rolled sheets of rPET are then fed into thermoforming machines where the trays are formed. The thermoforming stage yields good trays, as well as defect waste trays and skeletal waste. Other waste also arises from edge trimmings associated with the extrusion process.

2.2 Scope

In accordance with PAS 2050[11], the functional unit for this study was chosen to be a 16.6g rPET tray.Figure 1 shows the process map for the study, which, along with the system boundary, shows whatlife cycle stages are includedin the scope of the study:

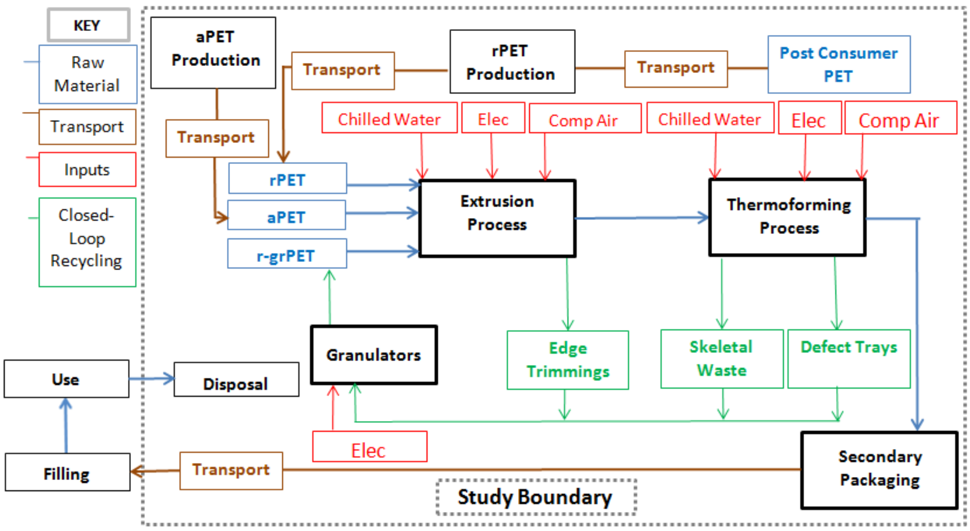

Figure 1: Process Map

In addition to the tray production process and the three raw material inputs outlined in Section 2.1, transportof the tray up to the point of filling, as well as itsend-of-life treatment, were included in the study. Secondary packaging use in the form of cardboard and LDPE (low-density polyethylene) bags and stretch wrap was also taken into account. Emissions factors for secondary packaging and end-of-life scenarios were sourced usingSimaProsoftware [12], while data on Irish grid electricity was sourced from the EPA [13]. Transport modelling using Gabi software was based on a 32 tonne Euro 4 emissions standard truck [14]. The CFs for raw material inputs as they arrived at Holfeld Plastics were calculated using SimaPro software [12].

2.3 Data Collection

In accordance with PAS 2050,primary activity data was collected for the relevant processes operated by Holfeld Plastics Ltd[11]. Anelectricity meter, airflow meter and chilled water energy meterwere installed on a thermoforming machine. The coefficient of performance (COP) of the chillers and the volumetric energy consumption of the compressors ($kWh.m^{-3}$) wereused to calculate the electrical power consumed(kWh) in chilled water consumption and compressed air supply respectively. The operation of the premises must also be included under PAS 2050[11]and therefore was considered in the study.GHGs arising from the premises operation included:on-site forklift operation and lighting. Lighting was allocated on the basis of floor space and residence time of the product as suggested by PAS 2050 (Clause 6.4.5) [11].Forklift operation was allocated on the basis of proportion of the functional unit of total annual throughput. Buildings are heated by a closed loop heat recovery system that utilises the return (hot) stream from the chilled water supply to thermoforming machines and therefore is not explicitly included in the study.

2.4 CF Calculation

The CF of an activity is calculated by multiplying the activity data (e.g., kg raw material) by the emissions factor for that activity (e.g., kg CO_2e per kg raw material). The total CF is calculated by then summing the individual CFs for each activity:

$$Carbon\ footprint = \Sigma\ Activity \times Activity\ emission\ factor \quad (1)$$

The results of the model that was developed in this work were compared to a previous in-house study, which used entirely secondary data for the same life cycle, and were found to agree to within ±10%. The main source of discrepancy arose from the production stage where the in-house study used estimated as opposed to measured activity data.

3. RESULTS & DISCUSSION

The CF of a typical 16.6g tray containing 15% vPET, 42.5% rPET and 42.5% r-grPET was found to be 23.42 gCO_2e, or 1.4106$kgCO_2$e $.kg^{-1}$ trays.Examining Figure 2, the biggest contributor to the CF was found to be the raw material inputs which contributed 45% of the GHGs, followed by tray manufacture which contributed 33%, and finally theend-of-life disposal which contributed 18% of the total GHGs. Transport was found to only contribute 2% of total GHGs but had the impact associated with transport of the filling been included, this figure would have been higher. The figure for transport only accounts for transport of the tray itself and does not include transport of raw materials, which was accounted forin the respective raw material CFs, and therefore is included in the overall study/analysis.

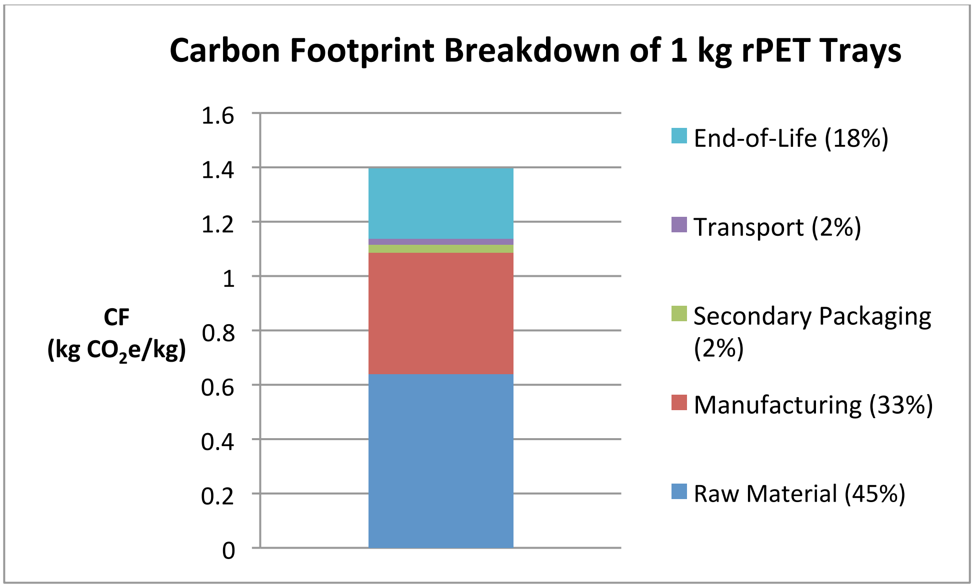

Figure 2: Specific Carbon Footprint Breakdown of rPET Trays(on a 1 kg basis)

3.1 Transport

A 10% increase in truck transport fuel efficiency, attainable through measures such as reducing driving speed and idling time[15]was found to have little reducing effect on the total CF (0.2% reduction), but had the use phase (food producer, retailer and consumer) of the tray and any associated transport been included, then a larger reduction would likely to have been observed by these measures.

3.2 Recycled Content

The recycled content of the tray was found to have a significant effect on the CF. Examining Figure 3, it can be seen that had the trays been manufactured from 100% vPET the CF would have been 3.567kg CO_2e .kg^{-1}. By currently manufacturing the trays using 85% recycled content, the CF is reduced by 60% (2.156kg CO_2e .kg^{-1}) compared to if 100% vPET was used. If the tray was manufactured with 100% recycled content, its CF would decrease further by 27% (0.03805 kg CO_2e .kg^{-1}) from the current 85% recycled content situation. This could be achieved as sheets are currently extruded with a virgin layer on each side for sealing purposes, however certain trays (e.g., mushroom trays) do not require sealing and hence could be extruded with 100% recycled content and therefore achieve a significantly lower CF.

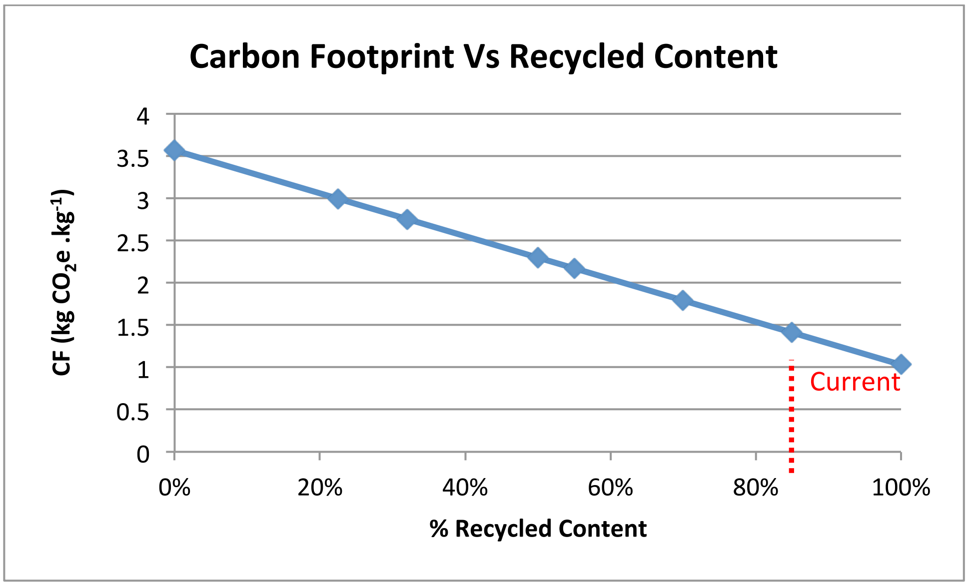

Figure 3: Carbon Footprint Vs Tray Recycled Content

3.3 End-of-life Treatment

The trays under examination in this study typically undergo an end-of-life process in the UK. The waste treatment statistics for plastic packaging in the total waste stream for the UK in 2007 were: landfill 68.5%, recycling 22.5%, incineration with energy recovery 1.1%, incineration without energy recovery 7.9% [16]. In this study, all incineration was assumed to operate with energy recovery, as more recent statistics for municipal solid waste (MSW) show that traditional incineration is being phased out for incineration with energy recovery [17]. Under PAS 2050, GHGs arising from end-of-life recycling of the product are not included in the CF, they are instead incorporated into the product that uses the recycled material as an input [11]. In addition to the current situation, the current situation if no recycling took place was also analysed (88.4% landfill (L) and 11.6% incineration (I)). The UK target for the recycling rate of its plastic packaging waste for 2011 is 32% [18]. This target scenario, with L and I waste treatments scaled accordingly (60L/8I/32R), is analysed. Finally, a likely future scenario, where 50% of plastic packaging is recycled (44L/6I/50R) is also analysed. Figure 4 shows the GHG benefits of increasing the recycling rate.

By currently recycling 22.5% of trays, the CF is 5.4% lower than if no recycling was implemented (0.0749 kg CO_2e $.kg^{-1}$). If the 32% recycling rate target is met, it will reduce the CF of the trays further by 2.3% (0.0316 $kgCO_2e.kg^{-1}$) compared to the current situation, while a 50% tray recycling rate will reduce the CF further by 6.6% (0.092 $kgCO_2e.kg^{-1}$) compared to the current situation. These results assume that the proportions of landfill and incineration of the remaining waste to be treated remain the same, which is unlikely in the future as MSW is predicted to increase. Moreover, the EU Commission is trying to reduce the amount of waste being landfilled, due the associated solid waste and energy consumption disadvantages (landfill is preferable over incineration from a CF perspective, but not from an energy consumption perspective).

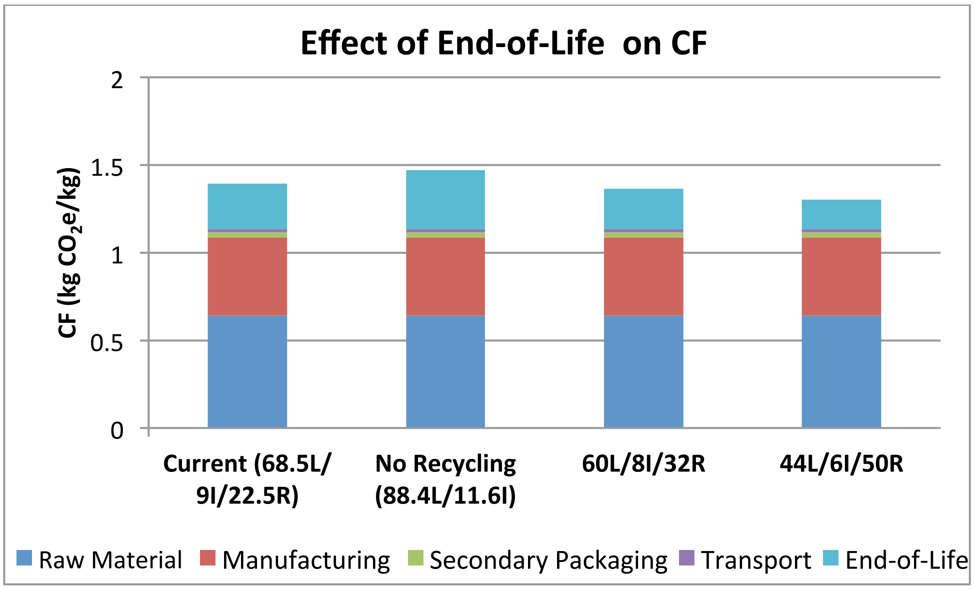

Figure 4: Effect of End-of-Life on CF

4. CONCLUSIONS

Using the PAS 2050 CF standard, this work calculated the CF of a 16.6g rPET tray to be 23.42 g CO_2e, or 1.4106kgCO_2e.kg^{-1} trays.Further investigation revealed that the CF associated with the raw materials inputs and manufacturing process contributed most to the CF (45% and 33% respectively). The end-of-life stage was found to contribute 18% of the total CF, while the secondary packaging and transport stages contributed only 2% each. By manufacturing the tray with 85% recycled content,the CF was found to be 60% lower than had only virgin material been used. By further increasing end-of-life recycling rates in line with current (32R) and likely future (50R) targets, the CF will be reduced by 2% and 6% respectively beyond the current (22.5R) situation. Improving transport fuel efficiency (regarding the manufactured tray only) by 10%was found to have a minimal (0.2%) reducing effect on the CF. It is suggested that to further reduce the CF of anrPET tray, that 100% recycled material is used in sheet extrusion for trays that do not require sealing, that the recycling rate of trays is further increased in the end-of-life stage, and that tray design is further optimised to reduce the amount of raw material used. Further identifiable efficiencies within the manufacturing process and raw material sourcing should also be considered as plant and machinery upgrades are undertaken.

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